AUTOMATIC TEMPERATURE CONTROL IN BUILDINGS

BY

E. C. COOPER

ARMOUR INSTITUTE OF TECHNOLOGY

1917

AUTOMATIC TEMPERATURE CONTROL IN BUILDINGS

A THESIS

PRESENTED BY

EARL C. COOPER

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

MAY 31, 1917

APPROVED:

Professor of Mechanical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

TABLE OF CONTENTS.

LIST OF ILLUSTRATIONS.

P r e f a c e .

This thesis was undertaken with a view of developing a simple system of automatic temperature control in residences. In all the thousands of houses in this country, only a very small percentage, so small as to be practically negligable, contain automatic heat regulators. It has been shown from tests that in cases where automatic temperature control has been used in residences, fifteen to thirty percent saving has been effected on the coal pile. With the prospect of the world's coal supply being exhausted in a few years, and the cost of coal increasing from year to year, fifteen and thirty percent savings in the fuel consumption of the myriads of houses in the world are propositions well worth looking into. A house containing a furnace, the heat of which is not automatically regulated, is like a "rudderless ship at sea", an impossible combination.

Also, an immense amount of vital energy, which might be turned into dollars and cents, is wasted every winter when house holders attempt to obtain satisfaction from their heating systems: opening and shutting windows, turning off radiators, making numerous trips down to the basement to adjust dampers, and midnight sessions caused by neglected fires - not to mention family tribulations.

The writer a year or so ago formed the opinion that this problem should easily be solved by means of a thermost at and an electromagnet. This work was undertaken with a view of investigating the possibilities along these lines. After making careful study of the records of the United States Patent Office, and the present heat regulators upon the market, together with all of the present heating and ventilating systems and automatic appliances, a magnetic regulating principle was worked out which should solve the problem.

The writer wishes to express his appreciation to those members of the faculty of Armour Institute who assisted him in this undertaking. I am especially indebted to Professor J. C. Peebles, Professors G.E.Marsh, Professor C. A. Nash, and Professor Nutting, Mr. Johnson, laboratory engineer, of the Chicago Bureau of Electrical Inspection, gave the writer a great deal of exceedingly useful information concerning the house wiring regulations of the Electrical Code.

E. C. Cooper.

Armour Institute of Technology.

May 31st, 1917.

THE PRESENT SYSTEMS OF AUTOMATIC TEMPERATURE CONTROL.

The subject of "Automatic Temperature Control in Buildings" received no consideration until about 1870. About this time a number of American inventors took up the problem, and after considerable experimentation Professor Johnson, of the Johnson Service Company of Milwaukee perfected the compressed air system which is used now in all of our large modern office buildings.

In large installations, very good results are obtained with the compressed air system of regulation, because an engineer is always available to keep the sistem in operation.

The apparatus required when compressed air is used as the motive power, presents undesirable complications and elements of unreliability, when installed in residences, where no skilled mechanic is available as a rule to keep it in working order. For this reason an arrangement which completely solves

the problem in large buildings is impractical in the millions of residences in the world.

To meet this demand, a great many electric systems have been designed, most of which have been failures because of the hopeless complications involved. Those which have been successful have only had a limited use, because complications are involved which the average man does not want to be bothered with. In the present electrical regulators, the motor which controls the damper of the furnace, is an exceedingly complicated devise, consisting of a number of gears cams and magnet relays, and usually an electric motor. When the average man is shown a catalogue of one of these regulators, he will not give it a second look, much less pay out 20 to 50 dollars for the purchase and installation.

Most of the electric regulators consist of a small high speed motor, geared down by means of a number of brass gears

to give a slow powerful movement of the damper. The current has to be automatically cut out, or prohibitive power consumption would result, and to get around this, a magnetically operated cam is required.

There are a few regulators on the market which perform the function of moving the damper by means of a wound up spring motor, or by means of a couple of weights like a grandfather's clock. These devices present the same complications as the other regulators and have the disadvantage of not being truly automatic, since they have to be wound up at intervals. Unfortunately, they usually run down at the wrong time, in the middle of the night or when the family is away. The mechanism is usually so constructed that when run down the damper is closed; but then the fire goes out causing great inconveniences.

In the thousand of apartment buildings throughout this country (the writer is not

in a position to make a statement concerning England, France and Germany, etc. although the same condition undoubtedly exists) except in rare cases, the heat is permitted to run wild. Compressed air systems are not reliable, and the electric regulators which are used to some extent in residences are not practical because the heat requirements of each apartment are different. One way to get around this would be to so design the piping that one valve could control the heat of an apartment. The extra expense of running up a single lead and then branching out from this lead at each floor would be very little greater than running up a lead to each radiator. There would probably be a few feet difference in piping. Cast iron pipe cost only about six cents a foot. This, however, is not done because electric regulators are at present so complicated that they are considered as a luxury, not a necessity. Then, too, there are a vast number of small stores which might

be regulated by one valve, but are not for the reason just stated.

It has been shown that 20% of the coal pile on an average is saved when automatic heat regulating mechanisms are installed. With the cost of coal steadily increasing, and our mines being slowly exhausted, automatic heat regulation, outside of the comofrt element, is becoming to be an economic necessity.

The various street cars and railroads are just beginning to instal thermostats. The writer has been unable to obtain details concerning them, because the patents are not yet complete, and are being kept secret. Thermostatic control in electric cars is not as difficult as in some other cases, since it is merely a small electric switch that has to be moved.

COST OF MATERIALS.

The cost of raw materials used in heat regulating apparatus, and the cost of manufacturing, is a subject of minor importance. After the parts have been standardized, they can be manufactured in la rge quantities, for a small cost compared to the selling price. For instance an electric thermostat consisting of a welded bimetallic bar, enclosed by a little casing, sells for ten dollars. Competition in the automatic heat regulating business has not yet reached a point where one firm may sell apparatus a few dollars cheaper than the other firms and gain any material advantage. A notable instance of this, occurred several years ago, when the United States government erected the Bureau of Standard's buildings in Washington. The Powers System of regulation was chosen, because on special tests which were made, the Power's system proved to be slightly more

dependable than the others, although it cost more. Any increase in dependability will justify the use of more material, andlabor in the construction of the apparatus.

FACTORS INFLUENCING DEPENDABILITY.

In large compressed air installations, very excellent results are obtained. There is very little chance of the motors which operate the valves or dampers getting out of order. The motor is extremely simple. It consists of a diaphram which expands or contracts in response to the pressure of the air within it. A few years ago the diaphrams were made of rubber, the life of which was about one year. Every year new diaphrams had to be put in. Lately, however, a one piece, brass, bellows has been developed which lasts indefinitely. The air compressor is always kept in working order by the engineers who run the power plant. This leaves, only, the thermostat to be considered. The thermostat is a very delicate little mechanism. A very slight expansion of the thermostatic material, has to move a needle valve, thru a lever. The amount of expansion obtained for one degree Fah., is less than one hundredth of an inch. The difficulties

which result from this small movement have been eliminated by careful design, and provided no one tampers with the thermostat very satisfactory results will be obtained. To get around this latter trouble, the thermostats are usually sealed, and the engineer called up when the temperature of the room proves unsatisfactory.

In electric systems, the whole difficulty lies in the motors. The thermostat, although quite a delicate piece of mechanism, has proven to be very satisfactory. A rise of one degree in temperature, only produces a movement of the bimetallic bar between the contacts of about the thickness of a piece of paper. However, if the room is kept between the limits of 65 and 72° F. satisfaction will be obtained. This fact accounts for the success of the electric thermostat. A change of three or four degrees of temperature, produces quite a deflection of the bimetallic bar. Authorities do not agree as to the correct temperature

of living rooms. Some say 65 and others as high as 70. About 72^{o} F. however, the heat begins to be oppressive. The platinum contacts of electric thermostats, wear slightly, and require adjusting about once a year. This adjusting is a very simple proposition; any child can do it. All that is necessary, is to wait until the rooms reach a temperature of 70^{o}, as indicated by a mercury thermometer, and then adjust the contact screws until a piece of paper will just slip thru the contacts. The ease with which electric thermostats may be adjusted, gives them a very great advantage over compressed air thermostats. A needle valve mechanism cannot be adjusted by a piece of paper. If an ordinary person attempts to adjust it, nine times out of ten the mechanism will be put out of commission for good. A great deal of trouble has been experienced in school installations, where the instructors, and sometimes the students, attempt to adjust compressed air thermostats, instead of calling

up the engineer.

The difficulty experienced with the electric motors, results from the attention necessary to keep them in working order. A high speed electric motor, with reduction gearing, and a magnetically controlled cut out cam, cannot be installed in a basement and permanently sealed. The mechanism has to be oiled, and cleaned occasionally. If this is neglected, the mechanism is ruined. Then too, the complexity and size of the apparatus, prevents it from being used except in limited cases. For instance it would be impractical to use it on a radiator to control the valve.

THE DEMAND FOR A MAGNETIC REGULATOR.

From the above discussion it may be seen that if a more simple devise could be developed to control the damper, the heat regulation problem in residences would be solved. What is needed is a simple, dependable, mechanism, which may be installed, sealed up, and never looked at or thought of again. All that

would be required would be to adjust the contacts of the thermostat, by means of a piece of paper, once a year, which is a very trivial requirement.

The only possibility of cutting down on the complexity of the high speed, electric motor, and gearing, is to use an electromagnet, which will move the damper or valve as the case may be, with a single stroke. A mechanism of this kind could very easily be designed so as to exclude dust and dirt, and would require no oiling. Further a very great degree of dependability would be obtained, because of the abscense of high speed revolving parts.

When houses are put up at the present time, the heating system is put in without any thought of automatic temperature control. The heating contractors do not concern themselves with electric regulators, or in fact, anything electrical if they can avoid it. Some ten or fifteen years after the house is put up, the owner gets disgusted with the inefficiency of

his heating system and puts in an electric regulator. If a suitable magnetic regulator could be designed the apparatus, because of its smallness and simplicity could be made an integral part of the furnace, and installed with furnace. Thus all that would be necessary, would be to run an electric cable down to the furnace. This could be easily done by the electrician that wires the house. In this way a great saving of labor would be affected.

When furnaces are automatically controlled, it is customary to operate both a damper and a check. In this way a quick response of the furnace to the thermostat is obtained. In making the magnet mechanism an intregal, part of the furnace, both damper and check could be easily combined, by taking the air supply under the furnace, from the rear, and having the check passage lead up perpendicular from the under passage. In this way both passages are controlled by one damper. Several patents, by different inventors have been taken out on this identi-

cal proposition; but the magnetic regulators proved to be failures.

Because of the small size of a magnetic regulator, it could very easily be applied to individual radiators. In some cases it is necessary to regulate individual radiators. This is done at present in a number of wealthy homes, by a rather unique application of the Sylphon brass bellows.

A metal insulated cover is put over the entire radiator, which practically insulates the radiator from the room when the steam is turned on. An expansible fluid in the brass bellows expands as the temperature of the room rises and operates a series of little doors near the top of the casing. When these doors are opened, air comes in thru the bottom of the casing and flows out thru the doors, heating the room. Whether the doors are open or closed, there will be considerable convection from under the radiator, but opening the doors, greatly increases the

convection. An opening in one end of the casing, out of direct line of the air currents, admitts air from the room to the regulator. The difficulty here, is that the temperature of the air near the radiator is always very much greater than in the rest of the room. There is always a definite ratio or gradient however, for any particular weather condition. It is due to this fact, that this apparatus has been fairly satisfactory. The weather conditions however are constantly changing.

A much better way to effect the above result would be to control the doors magnetically. Because of the small force necessary to move these doors, a very small electromagnet would be needed. This would eliminate all multiplying levers and springs, and greatly increase the dependability, besides having the control at a point some distance from the regulator instead of right near it.

A magnet regulator would work very well when applied to one valve, which controls an

entire apartment. In the apparatus described above, all troubles due to leaky valves are avoided, but in the case now under consideration to obtain best results, the valves should be designed so that the seats and discs can be changed if necessary.

A very efficient design could be affected if magnetic control were applied to cars, heated electrically. The magnet could be operated by one or two dry cells, or a dry cell and a relay. 110 volts cannot be used across the contacts of a thermostat. The dielectric strength of the air is not sufficient to prevent the current from jumping across the contacts which are only about a hundredth of an inch apart when the circuit is open. There are various other applications for a magnetic regulator, one of which is in residences receiving heat from central heating plants.

The difficulty which has arisen in attempting to apply magnetic control, arises from the fact that with the exception of a few rare cases,

the power consumption of the magnet will prove prohibitive unless the current is automatically shut off after the magnet has performed its function. When only a small switch has to be moved, as on a street car, or a door in a radiator casing has to be opened the power consumption may not prove excessive. That the power consumption will be excessive unless, the current is cut out, can be seen from the calculations at the end of this thesis. For various reasons it is necessary to use a large number of turns of small wire, and the I^2 R loss resulting is prohibitive, possibly over 100 watts.

No good housewife would want a 100 watt lamp burning all day if there were a way of avoiding it.

This statement may be modified, however, when A.C. current is to be used. In some cases, such as in residences where there is only one regulator to be installed the design may be made to consume only about 25 watts.

This may be done by increasing the size of the wire and the core, and utilizing the inductive effect of the magnet to cut down the current, instead of resistance, which will be about 5 ohms in place of 20 with the cut out mechanism. There is a great misapprehension on the part of the majority of practical engineers concerning alternating current phoenomena, which accounts for the fact that the electric heat regulating companies have not put out an A.C. magnet regulator. It is commonly thought that the power consumption or alternating current circuits is the product of the current and voltage, the same as on direct current. This is not true - the power is E 1 cos θ, the angle θ referring to certain vertar quantities, when the solution is made graphically; or what is the same thing, the power consumption is the same as on direct current, I^2R, where R is the resistance of the wires. The inductive impedance does not consume power, but merely excercises a choking effect. This is the principle of the theatre dimmed.

In A.C. magnets, lamination is necessary. The latest improved electrical sheets sheets upon the market have a power loss due to eddy current and hysteresis of three watts per pound, at 60 cycles and 14,000 induction.

Assuming a 25 watt loss, the cost of current would be about three dollars a heating season, or about two cents a day. (Cost of Edison service 6¢ per hr). The three dollars lost during one heating season would more than pay for the extra labor necessary in the cut out mechanism. The material used is about the same in each case.

In a great majority of the houses where these regulators would be installed, the three dollars a year would not be missed. The saving in coal would amount to about $10. dollars, assuming $50 total coal cost and a 20% saving due to automatic control. Then, the increased dependability due to the extreme simplicity of design of a non-cut out magnet, would perhaps in all cases, justify its use in

residences. In appartment buildings, however, the cost would be some multiple of three dollars and automatic cut out magnets would affect considerable saving.

The writer in this thesis, has included formulas, and calculations which verify the statements being made. The formulas are authentic, having been tested out innumerable times, practically. Some of them are the results of practical experiments.

In order to make this research exhaustive, the writer made a careful study of all of the automatic heat regulating attemps which have been recorded in the United States Patent Office, since the office first opened. (with the exception of those destroyed in the fire a number of years ago. At that time, however, electricity was in its infancy). The writer made it a point to obtain the idea involved, in every patent which had not the appearance of being too hopelessly complicated for practical application. The ingenuity displayed in some

of these designs is remarkable, and extremely interesting and instructive. The writer read a great number of these patent descriptions in detail, especially the attempts of Professor Johnson of the Johnson Service Co., and Mr. Powers, and others of late years.

Of all the attempts to design magnetic regulators, not a thing has been done along the line of alternating current magnets. The inventors encountered the difficulty of excessive direct current power consumption, and then turned their efforts to perfecting an automatic cut out devise. All sorts of cams, gears, levers, and clock work, were combined together to obtain a cut out mechanism. These designs were very ingenious, and without a doubt could all be made to work - but not practically. The writer after making a profitable study of past failures, and after making a number of trial calculations and sketches has been fortunate enough to conceive of a means of affecting the regulation with,

and without an automatic or cut out devise, as the case may be. In some cases the small size of the magnet involved will not necessitate a cut out devise; but in cases where the cut out is necessary, the choking effect of alternating current inductance will be employed to supply the necessary impetence in the equation,

$$I = \frac{E}{Z}$$

I = current in amperes

E = Impressed voltage.

$$Z = \overline{R^2 \ x \ (2 \ \pi \ f \ L)^2}$$

R = resistance in ohms.

F = 60 cycles

L = inductance in Henries

By making ($2 \pi F L$) large in comparison to R, a small power factor may be obtained in the equation:

$$P = E \ I \cos \theta$$

P = power consumption in watts.

$$\cos \theta = \frac{R}{R^2 \ x \ 2 \ \pi \ f \ L}$$

These are fundamental alternating current equations, and the proofs will not be attempted here.

In the calculations shown later, the inductance formula from which (L) is obtained is only approximate, the same as all electrical designs. It is immaterial to the writer whether the formula departs 50% from the truth one way or the other. The dimensions of the magnets made be modified to compensate the error. In most electrical designs, several experimental designs have to be actually constructed before the correct one is obtained. All that is being attempted in this thesis is to show that these new designs are possible.

To effect the automatic cut out, two magnets are used, a power magnet and an auxiliary magnet to release the power magnet. This devise together with drawings and a description is shown later. It might be stated here that this principle is the only one of all other possible conceptions, which will be a practical success. The possible combinations are limited, and with

the exception of the principle under discussion have all been tryed, and have all failed. Before describing this principle in detail, we will give a brief discussion of these failures and all past attempts in general.

WORK OF JOHNSON, FORTIER & POWERS.

Our present systems of heat regulation in large buildings are the result of the work of W. S. Johnson, and C. L. Fortier. In the years 1910 and '13, D. J. Powers of the present Powers Heat Regulating Co., patented several novel variations of the Johnson system, which have proved to be a commercial succes; but it very questionable as to whether they embody any improvements on the Johnson systems or not. W. S. Johnson and C.L. Fortier were assignors to the Johnson Electric Service Company, of Milwaukee, Wisconsin, in the years 1884 and 1885, when the extensive experimental work along heat regulating lines started. The Johnson Electric Service Co. has developed into the present Johnson Service Co. which installs compressed air heat regulating systems all over the world.

W. S. Johnson took out his first patent on heat regulating apparatus, April 29, 1884. This first attempt consisted of an electro-

magnet, which upon energization, closed the valve of a steam or hot water radiator. (Radiators at this time were all constructed of ordinary pieces of cylindrical piping joined together at the ends by elbows.) No automatic cut out mechanism was provided, so that the current was continuously in the circuit when the valve was closed. The electro-magnet consisted of a solenoid with its core stationary, and projecting a little from each end. A small air gap was obtained by making the armature part of a lever which moved the valve. This was an incorrect electrical design, and only a very small pull would be possible at an extravagent power consumption, especially, on continuous current. Armature magnets should always have an iron return path, instead of an air return path, so as to reduce magnetic leakage. The valves of this heating system were to be operated by direct current, in the form of wet cells or a dynamo. As was found out later when this design was constructed, no

batteries would stand up under such severe usage. The battery deterioration would be very rapid. It was also found out that no matter what kind of a direct current generator was used the cost of power was prohibitive. Alternating current application was not considered. Today, we have data and practical formulas available with which to calculate power consumption in electro-magnets, chiefly because of the work of Mr. Charles R. Underhill. In 1884 Mr. Underhill's experiments had not yet been conducted, and consequently, power consumption had to be determined by experiment.

The mechanical design of this valve was not very good. Even if no electrical difficulties were experienced, the valve would have been too clumsy to have been a commercial success.

June 24, 1884, a patent was granted W. S. Johnson, whereby the valve was to be operated by fluid pressure (liquid or gas); and an auxilliary electric valve was to control the flow of the fluid into the diaphram. No cut

out arrangement was provided for the magnet, as before. This design had both the electric valve and the power valve situated at the point at which the steam was to be controlled, and was too complicated to be successful commercially. The second design was patented, merely as a modification of the first. In both cases the current of the magnets was not automatically cut out.

After the previously mentioned systems were constructed and experimented with, it was found that the current consumption was excessive. May 18, 1886, Mr. Johnson obtained a patent for a system similar to the one just described, excepting that the current was automatically cut out and the electric valve was separate from the power valve.

The electric valve was designed to control compressed air. Inside the mechanism, were two small valves to control the flow of the air; one was to let the air in and the other to exhaust it. The little air valves were

controlled by two magnets and an arm arrangement, besides a spring.

One of the magnets pulled a pivoted armature one way until the circuit was broken for the first magnet and completed for the second. The second magnet then operated in a similar manner. This principle has been tried in a great many designs and as a rule has not proven satisfactory. The movement is not positive, and when a spring is used, especially a small spring, the unreliability is more marked. Large springs are not necessarily objectionable in heat regulating apparatus, but small springs sooner or later crystalize and lose their resilience.

Apparatus covered under this third patent was installed in a number of buildings. In July 1916, the writer inspected one of these installations at the Englewood High School, Chicago. The engineer in charge of the power plant said that the apparatus required continual

adjusting, and had not given good satisfaction. In the new addition to the school which was under construction, a new system was to be installed.

In October, 1886 a new form of power valve was patented by Mr. Johnson, in which the air was exhausted from a cylinder by a vacuum pump, and the pressure of the atmospheric air moved a piston against the resistance of a spring. This was quite a novel design, but would not do practically because of complications and leakage through the piston rings, etc.

In patents issued to Mr. Johnson,

Nov. 2, 1886.
" 16, 1886.
Feb.21, 1888.
Mar. 6, 1888.

numerous details of construction of the various diaphrams, dampers, etc. entering into heat regulating systems were covered. In these patents a number of attempts were made to get a satisfactory automatic cut out mechanism,

which were all modifications of the two magnet principle.

May 1st, 1888, Mr. Johnson was granted a patent wherein he attempted to accomplish the automatic cut out by clockwork, wound up with a spring. This spring and gear arrangement was fastened under the thermostat. It is quite evident that this could not be a practical success, because of complications and unreliability involved.

In a patent issued to Mr. Johnson July, 16, 1895, the needle valve compressed air thermostat was brought out. The compressed air thermostat was designed to get around using electricity. No success was met with in the attempts to perfect a satisfactory automatic cut out mechanism. A great many of the installations were operated without automatic cut out mechanisms, and excessive maintenance cost occurred. Mr. Johnson says, in this patent, "My present invention is the result of ten years' extended experience, and its object

is to produce an apparatus which will secure the advantages of prior classes, but which can be made and maintained at a lower cost." Thus, the use of electricity was given up as a failure.

December 24, 1895 C.L. Fortier, was granted a patent, in which another attempt was made to automatically cut out the current. To accomplish this, Fortier used an extremely complicated arrangement of clockwork, magneto motors, and magnets. The complications involved were too great for practical success.

In May, 1896, Fortier developed another two magnet, automatic, cut out valve. The trouble with the two magnet principle is that, the weight of the armature or the tension of a spring cannot be used to ensure a tight closing of the valve, since the armature has to be balanced on the pivot. Thus if a little dirt should get on the valve seat, or a little wear should occur, the valve would leak like a sieve.

The present compressed air systems are all operated successfully by compressed air. If, however, it should be desirable at any time to use a combination compressed air and electric system, the writer's automatic cut out principle would be admirably adopted for such usage.

The same difficulty is encountered when attempting to apply the two magnet principle to radiator valves. A spring cannot be used to seat the disc firmly on its seat, and so a butterfly valve must be used. Butterfly valves are failures on radiators, because of the leakage which occurs when the valves wear.

F. E. Chatard, in 1892 was granted a patent, in which two vertical solenoids were to move a balanced cylindrical damper situated in a pipe at the rear of a furnace. The upper outlet of the pipe was to check combustion and the lower was to promote combustion. This design was provided with automatic cut out cams. In the design shown in the patent drawings, no attempt was made to protect the cut out cams

from dust. Also, in order to work satisfactorily, the cylinder would have to fit closely to the outer casing. If a little rusing occurred, the whole apparatus would be put out of commission. These difficulties could be overcome by a change in the design. The principle involved, however, is not positive; the cut out mechanism does not involve elements of absolute dependability. The kinematic outline of a heat regulator, must be so designed, that the mechanism cannot do anything else but work. This design although containing some possibilities has not been used. This principle cannot be adapted very well to alternating current. The same objections of unreliability, apply also to mechanisms having two magnets arranged horizontally.

As shown by a later patent, Nov. 23, 1897, Fortier abandoned automatic cut out designs, and perfected a continuous current, two magnet, air valve. No attempt was made to apply

alternating current. When the motive power is direct current, 110 volts, excessive power consumption will result if the current is continuously in the circuit. Batteries whether open or closed circuit have to be continually renewed, which is a nuisance and expense. A low voltage generator, of about fifteen volts output, or a low voltage motor generating set might be used advantageously in this connection. The ideal power for this case would be to use low voltage alterinating current, and substitute the inductance of the magnet coils for the resistance of the wires. Thus the power consumption per magnet would be negligable.

Mr. D. J. Powers in 1910, and 1913 brought out several improvements in large installations, such as the use of master thermostats, and graduated dampers.

For a period of over 30 years, a great many vibrating magnets have been experimented with, but with no success. The electric motor with all its gears and cams has been used in preference to a vibrating magnet mechanism. One objection to the vibrating magnets which have come to the writer's attention, is that spring contacts have been used, as in an electric bell or induction coil. Small springs are not absolutely dependable, but crystallize and wear out in a short time. This difficulty could be overcome by operating the contacts by gravity and avoiding the use of springs. Possibly a small amount of material might be saved by a vibrating magnet over a two magnet regulator, but just as much if not more room would be taken up. When the fact is considered that dependability, and not material is the controlling factor in heat regulating designs, it will be seen that the vibrating magnet cannot compare with a

two magnet regulator, because of the greater positiveness, and certainty in the latter.

ELECTRIC HEAT REGULATION IN CARS.

In the last two years (1915-'16) electric heat regulation has been receiving the attention of the various car companies. The Consolidated Car-Heating Company of West Virginia, and the Gold Car Heating & Lighting Company of New York, N.Y. have obtained six or seven patents on magnetic valves, and switches. They have perfected a simple magnetic valve without an automatic cut out mechanism but have not as yet succeeded in obtaining a suitable cut out devise, although the need of the latter is paramount.

MISCELLANEOUS DESIGNS.

In 1913 D. H. Darin of the Automatic Switch Company of New York patented a magnetic valve which was to utilize the momentum of the core to effect automatic cut out. A pivoted weight below the magnet, was to move alternating left and right, and open and close the valve against the tension of a spring. The valve was to be opened by means of the weight of a lever pressing on the valve stem. This was very much too small a force to be reliable on a leaky radiator valve. A very strong force is required to shut the valve tightly. Also, spring contacts were to be used. One magnet designs involve too many complications to be practical.

A design by I. M. Baldwin Feb. 29, 1916, brought out a very good electric motor valve. As far as the electric motor goes, this valve would be hard to improve upon. The objectionable feature of regulators operated by high speed motors is that the parts need oiling

frequently, and wear out. In order to reduce the high speed of the motor down to the slow speed of the valve, a number of gears are necessary, which together with the contacts and cut out cams form a very complicated mechanism.

One of the most recent regulators which has been put upon the market is operated entirely by oil. The oil in a cylinder acts as a thermostat, and transmits pressure to the valve by means of a long tube filled with oil. It is hardly likely that this regulator will meet with much practical use. Only a very small movement of the valve is obtained; and the pistons and springs involved make adjustment difficult. The whole mechanism is subject to leakage.

J. C. Horning of Chicago, brought out in 1914, a differential, pressure, and temperature valve control system, for use in houses obtaining heat from central stations. A spring arrangement keeps the pressure constant

and a thermostat the temperature. In the present commercial designs, an electric motor is used in conjunction with the thermostat. A magnetic regulator would contribute a great deal to the reliability.

DESCRIPTION OF APPARATUS.

The accompanying drawings show the principle of the writer's two magnet electric heat regulator. The mechanism is drawn full size (12" = 1 ft) and was designed for testing purposes. The greatest economy of materials is obtained by using just as small an air gap as possible. There is a limit practically to the size of air gap which may be used; the smaller the movement, the less dependable the mechanism within certain limits. The power magnet was designed to pull ond hundred pounds, and have a movement of one quarter of an inch. This regulator when tested will furnish valuable data, and a basis for future designs and improvements. For convenience in construction, the mechanism was built up of a number of small pieces, which may be all made in a machine shop. In this way a model may be made without going to the expense, time and trouble of making patterns and castings. The assembled drawings may possibly be elucidated

by the detailed drawings following them.

The regulator consists of two horseshoe magnets, one a power magnet designed to lift about one hundred pounds with an internal air gap of one sixteenth of an inch; and the other, an auxiliary magnet, to lift twenty pounds with an air gap of one sixteenth of an inch, and one and seven eighths pounds with an air gap of one quarter of an inch. The conical shaped arrangement of the core in the large magnet allows a movement of one quarter of an inch for an air gap of one sixteenth of an inch. The angle of the cone is 15^{o}.

Figure 1, shows a cross section of the regulator, thru the center of the power magnet. Figure 2, shows a plan view of the entire regulator, and also a plan view of the auxiliary magnets. Fig. 3, shows a side elevation of the regulator. Figure 4, shows the details of the cut out mechanism. Figure 5 shows the wiring diagram of the regulator

for use on 110 or 115 volt alternating current.

No springs are to be used in this regulator. For convenience in testing and to avoid the use of springs, the apparatus is designed so that it may be screwed to a wall or any convenient place, with the armature of the auxiliary magnet downward, in which position the armature will fall by its own weight. In its working position the regulator will be turned 90° clockwise from the position shown in figure 3, and secured by the screws indicated in the base of the same figure. The small piece at the top of the regulator shown in figures 1 and 3, was included to provide means for applying a load for testing.

As shown in figure 1, a rectangular piece of metal projects downward from the top of the armature of the large magnet, parallel to the cores of said magnet, thru the base of the magnet, and down between the cores of the auxiliary magnet. A piece projecting from the armature of the auxiliary, is so constructed as

to fit into a notch in the first piece. The ends of these two pieces engage the three contacts, shown in figure 4. The contacts are to operate by gravity, so as to avoid the use of small unreliable springs. The contacts are to be made of tungsten (if platinum proves too expensive), and are so designed that they will move one eighth or one quarter of an inch. Small chains form the conductors for the current, and at the same time facilitate the movement. In this way, wearing of the contacts will be compensated for, and the life will be prolonged. These contacts should last indefinitely. Excessive wearing at the contacts is also avoided in another way. 110 volts cannot be used across the contacts of an electrical thermostat. In the present electrical regulators which are on the market, a transformed is used when the motor is to be run by alternating current. The same transformed current which passes thru the thermostat and operates the magnet cams, runs the motor. The transformed voltage however

is not sufficient to operate magnet regulators.

To get around this difficulty and to increase the life of the contacts. The writer connects up his regulator in the following manner: the contacts are connected up to a little relay operated by transformed voltage. The transformed voltage passes thru the thermostat and the contacts of the regulator, and then energizes the relay which throws in the 110 volt current for the coils of the regulator. Relays operate easily on currents as low as one tenth of an ampere. In this way low voltage and low current passes thru the contacts of the regulator and 110 volts is only broken at the relay, where excessive wear is easily compensated for. Only two or three amperes will flow thru the 110 volt contacts. A wear of three quarters of an inch may be allowed for the 110 volt contacts. No springs will be necessary. The relay may be placed so that the armature will fall by its own

weight. Sticking of the armature will be prevented by brass or copper stops, which will prevent the armature from ever touching the core. The truth of these statements may be easily verified as follows: take a small, permanent horse-show-magnet with pole faces 1/2" x 1/8", and hold the armature against one pole and remove it from the other. The armature may easily be moved one inch from the pole face, and be attracted up again against its own weight. By using leverage if necessary and round pole faces, and, consequently, greater pole areas, a very positive relay may be designed. The magnetic phenomena involved in permanent magnets and in electromagnets is essentially the same. Ampere turns on electromagnets are required for two reasons: one, to magnetize the iron, the other, to overcome the reluctance of the air gap. The latter requires most of the ampere turns. In the calculations shown for the large magnet of the regulator, only 190 NI are required to energize the steel, against 3,660 for the air

gap. No steel may be magnetized above the saturation point, so the permanent magnet mentioned may be conceived of as being replaced by an electro-magnetic relay with about 200 NI, or less, because the dimensions of the relay will be very much less than those of the large magnet in the regulator. A problem which illustrates these points may be found on pages 44 and 45 of Gray's Principles and Practise of Electrical Engineering.

This particular regulator is designed to move ten pounds (dampers weigh only two or three pounds) two and one half inches, thru a lever. The exact movements and pulls, and complete designs for all the various cases which may arise in applying this principle to valves, furnaces, etc., cannot be undertaken in this thesis. One particular design is shown here which illustrates the principle that is common to all.

OPERATION OF REGULATOR.

Referring to figures 4 and 5, it will be seen that in this case where alternating current is to be used, two circuits are required, i. e., an one hundred and ten volt circuit and a transformed voltage circuit. The transformed voltage may be taken from any type of transformer. The same bell ringing transformer which rings the door bell of the house or apartment may operate the relay of the heat regulator.

Three contacts are used: one which the auxiliary magnets breaks, as its armature slips into the notch of the power armature piece, breaking the circuit of the power magnet after it has moved the damper; another, to be broken by the armature piece of the power magnet after the auxiliary magnet has been energized, and moved its armature piece out of the notch; and a third, which facilitates the movement of the auxiliary armature piece

out of the notch, by temporarily energizing the power movement, and so relieving the pressure in the notch caused by the weight of the damper. Without the third contact, excessive wear might occur in the notch, but by this arrangement wear is practically eliminated.
In figure 5, the letter c's represent locations of condenser connections in case excessive inductance is met within designs. As shown in the calculations it is hardly likely that condenser's will ever have to be used. Referring to figure 5, suppose that the auxiliary armature piece is to be pulled out of the notch, to release the power magnet, and to lower the damper of a furnace. The house at this time is beginning to get too warm, and the thermostat moves to the release contact, which energises both relays, and consequently both power and auxiliary magnets. The current from the bell ringing transformer circuit, passes thru relay N thru contact A, and thru relay M by contact C. Contact C, is broken by the armature piece

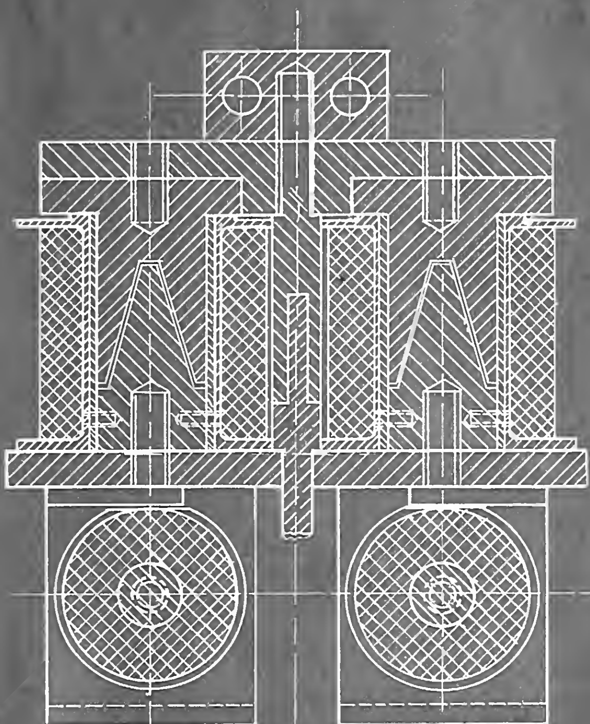
of magnet N, after the piece moves out of the notch. This deënergizes relay M, and consequently, magnet M. The armature of magnet M, then moves out, lowering the damper, and breaking contact A, deënergizing relay N, and consequently magnet N. Thus no current is flowing thru the apparatus. As the armature piece of the auxiliary magnet moved out of the notch contact B was completed, but no current flowed thru because the power contact of the thermostat was not completed.

When the house starts to cool off the thermostatic blade moves to the power contact. Relay M is energized by means of contact B. Power magnet M is then energized, and the armature moves in, opening the damper of the furnace. When the armature has completed its movement, the armature piece of the auxiliary falls by gravity into the notch of the armature piece of the power magnet. After it has fallen into the notch, contact B is broken, and no current flows thru the apparatus. We

are now where we started.

It will be observed that at E, the circuits of the three contacts combine into one circuit, and flow thru the metallic parts of the mechanism. This greatly simplifies the mechanical construction. A and C are always in use at the same time, anyways. When A and C are in, the current cannot flow thru B, because the power contact of the thermostat is not completed and vice versa. Although there is short connection between the two magnets, current cannot flow from B to A, because A is not completed when B is first completed. Later it does not matter.

(Note: In the practical application of this regulator, the wiring about the relay N will have to be changed, because in order to allow for wear, the contact A will have to be closed at the same time the power contact at the thermostat is completed. This change may be easily effected.



SECTION THRU CENTER

SCALE:- 1/2" = 1 FT.

FIGURE 1

E.C. COOPER
3/20/17

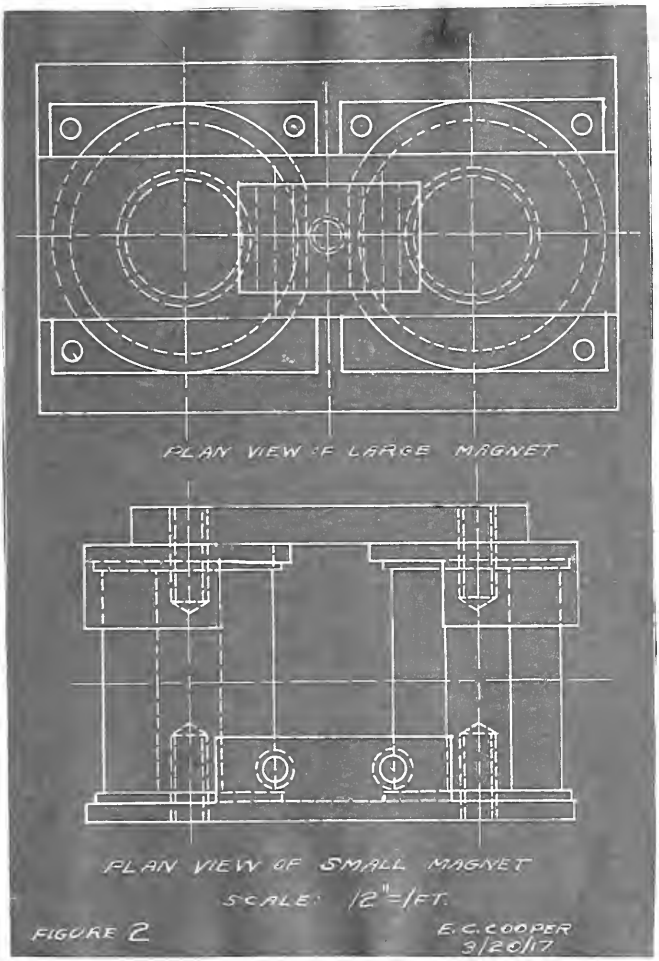
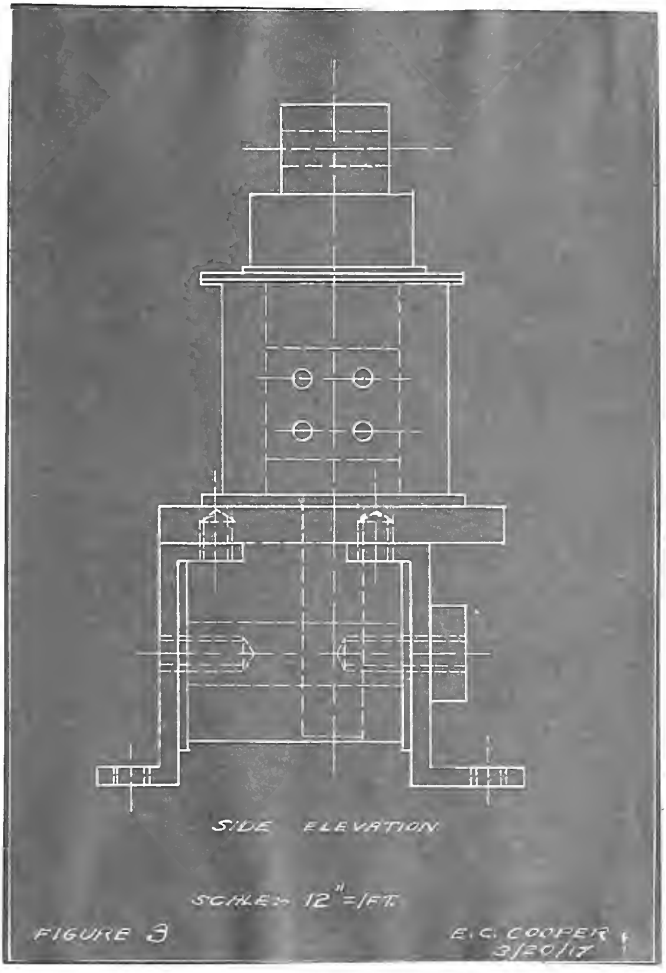
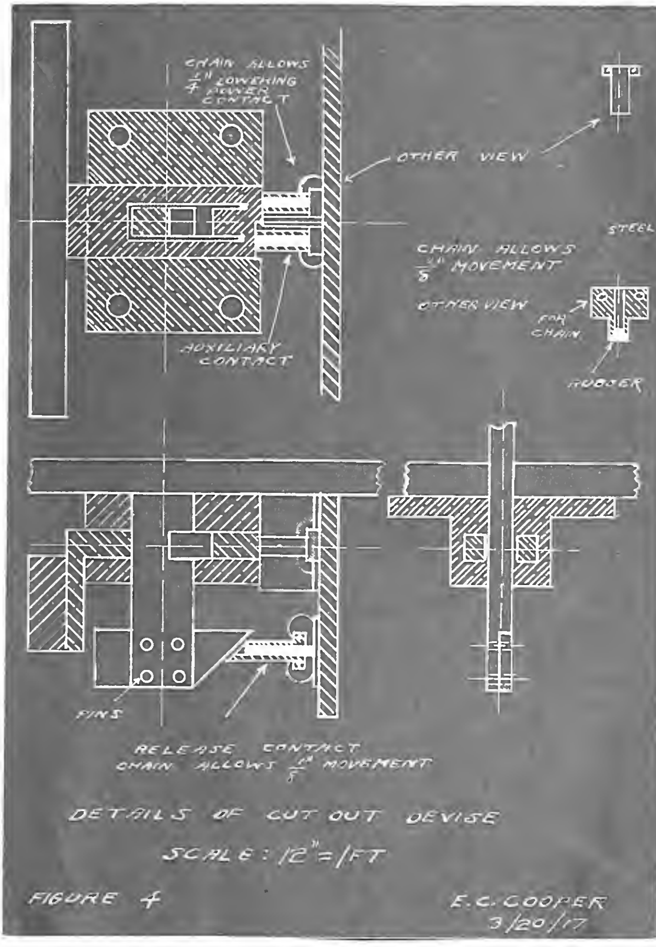
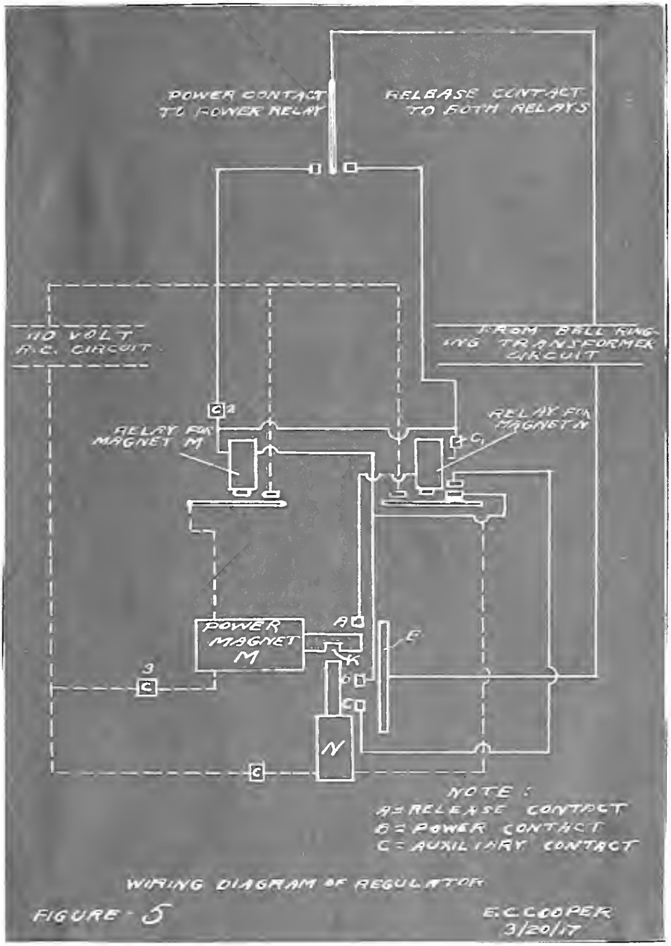
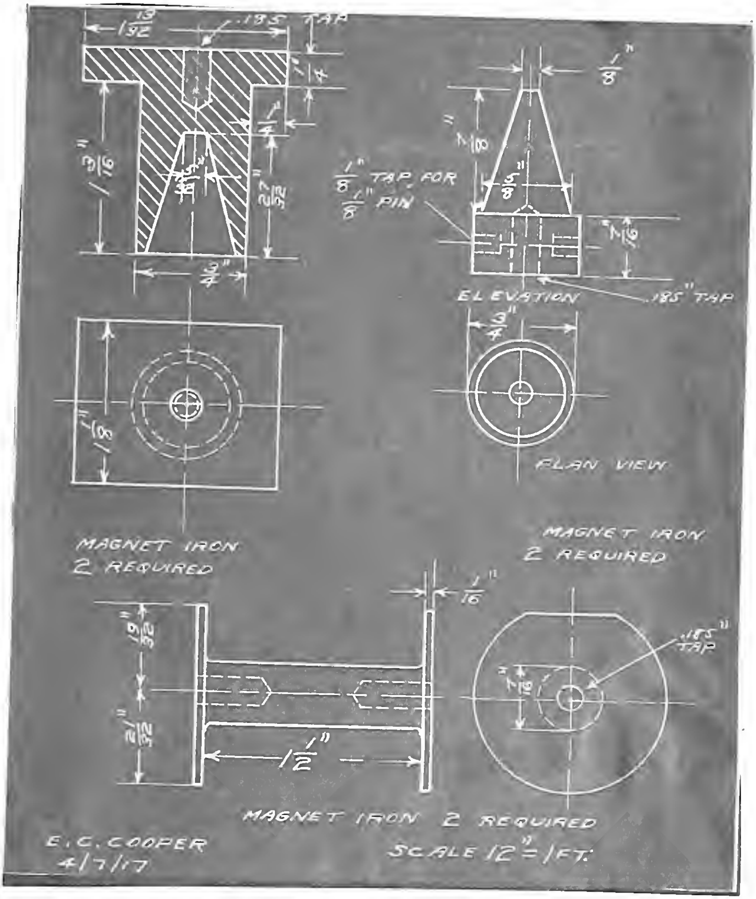

PLAN VIEW OF LARGE MAGNET
PLAN VIEW OF SMALL MAGNET
SCALE: 12"=1FT.
E.C. COOPER
3/20/17

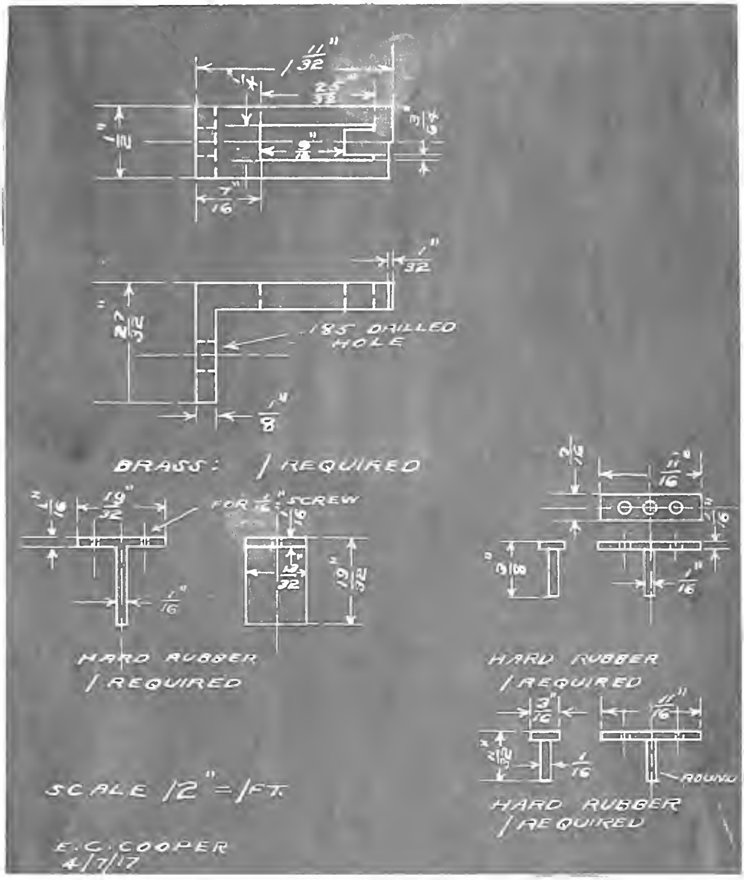
FIGURE 2

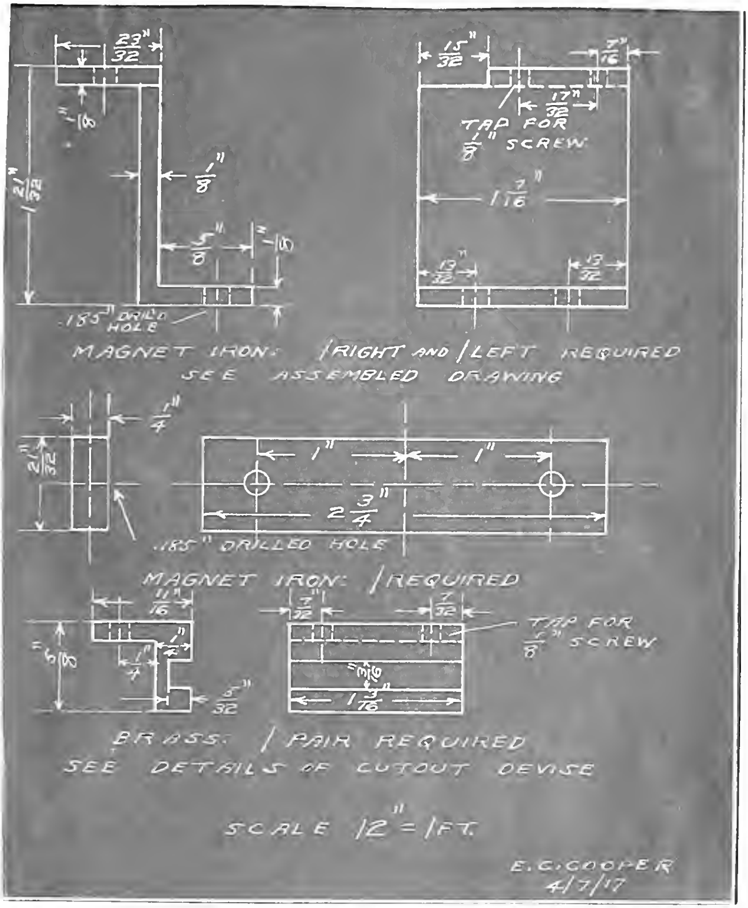

SIDE ELEVATION
SCALE: 12" = 1 FT.
FIGURE 3
E. C. COOPER
3/20/17


CHAIN ALLOWS 1/4" LOWERING POWER CONTACT
OTHER VIEW
STEEL
CHAIN ALLOWS 1/8" MOVEMENT
OTHER VIEW
FOR CHAIN
RUBBER
AUXILIARY CONTACT
PINS
RELEASE CONTACT
CHAIN ALLOWS 1/8" MOVEMENT
DETAILS OF CUT OUT DEVISE
SCALE: 12"=1FT
FIGURE 4
E.C. COOPER
3/20/17

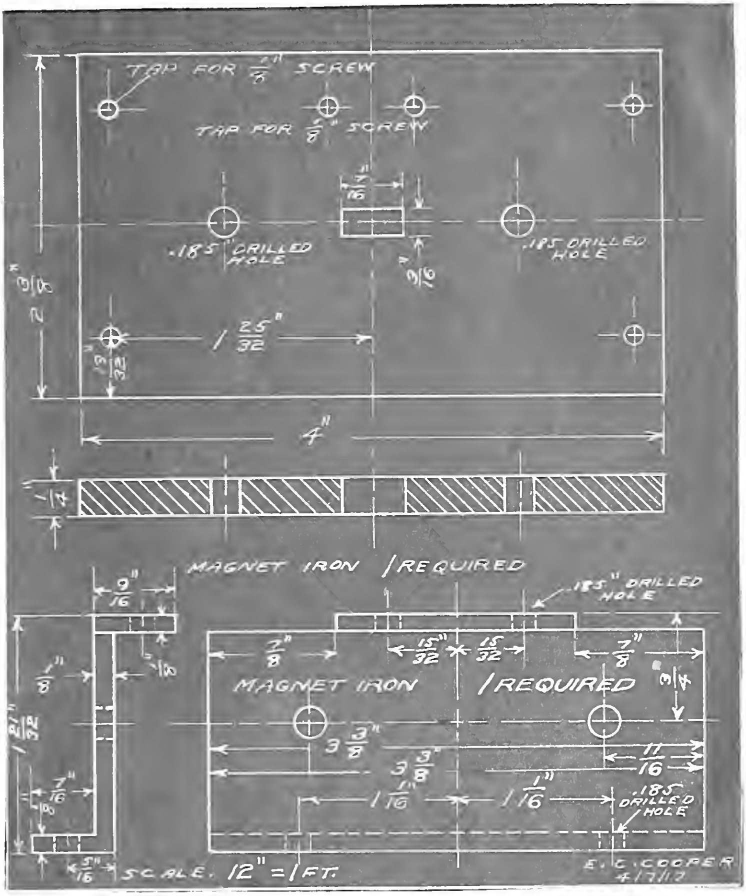

POWER CONTACT TO POWER RELAY
RELEASE CONTACT TO BOTH RELAYS
110 VOLT A.C. CIRCUIT
FROM BELL RINGING TRANSFORMER CIRCUIT
RELAY FOR MAGNET M
RELAY FOR MAGNET N
C2
C1
POWER MAGNET M
A
B
C
E
K
N
3
C
NOTE:
A = RELEASE CONTACT
B = POWER CONTACT
C = AUXILIARY CONTACT
WIRING DIAGRAM OF REGULATOR
FIGURE 5
E.C.COOPER
3/20/17


.185 TAP
1/8" TAP FOR 1/8" PIN
ELEVATION
.185" TAP
PLAN VIEW
MAGNET IRON
2 REQUIRED
MAGNET IRON
2 REQUIRED
.185" TAP
MAGNET IRON 2 REQUIRED
E. C. COOPER
4/7/17
SCALE 12" = 1 FT.

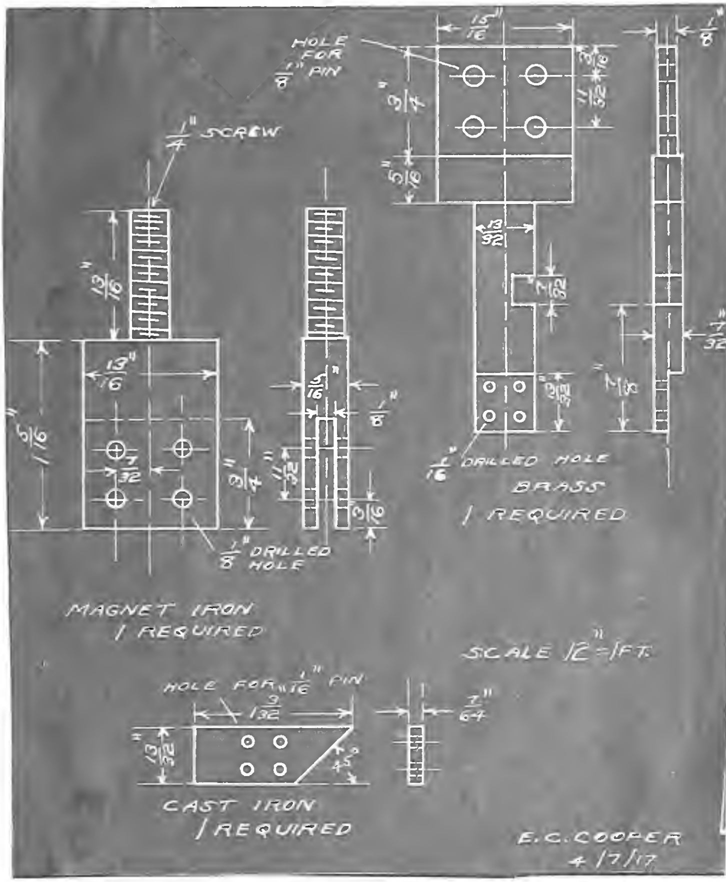

BRASS: 1 REQUIRED
.185 DRILLED HOLE
FOR SCREW
HARD RUBBER
1 REQUIRED
HARD RUBBER
1 REQUIRED
ROUND
HARD RUBBER
1 REQUIRED
SCALE 12" = 1 FT.
E. C. COOPER
4/7/17

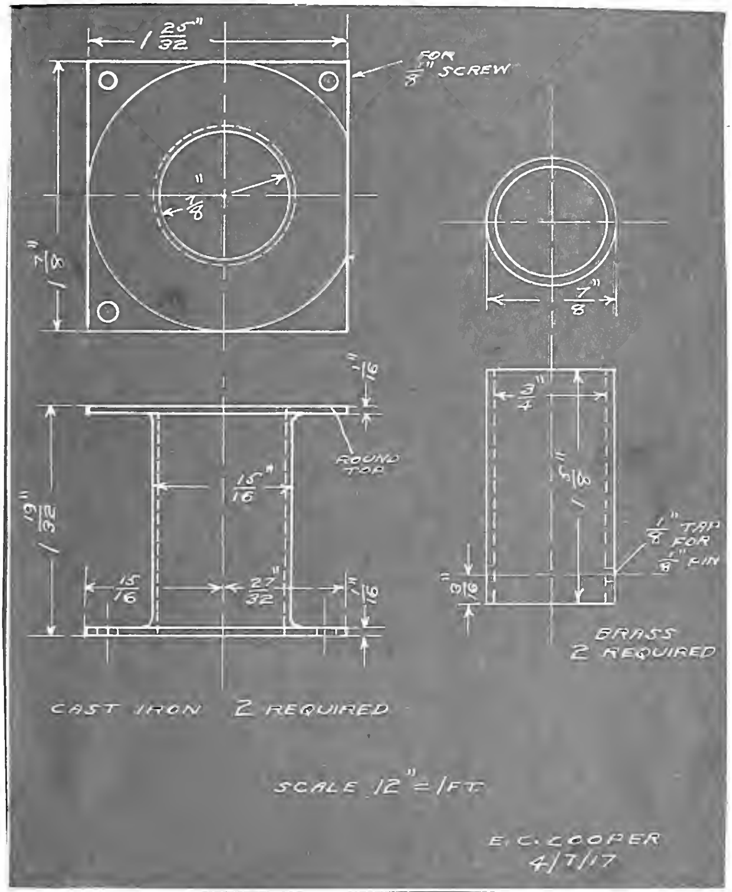


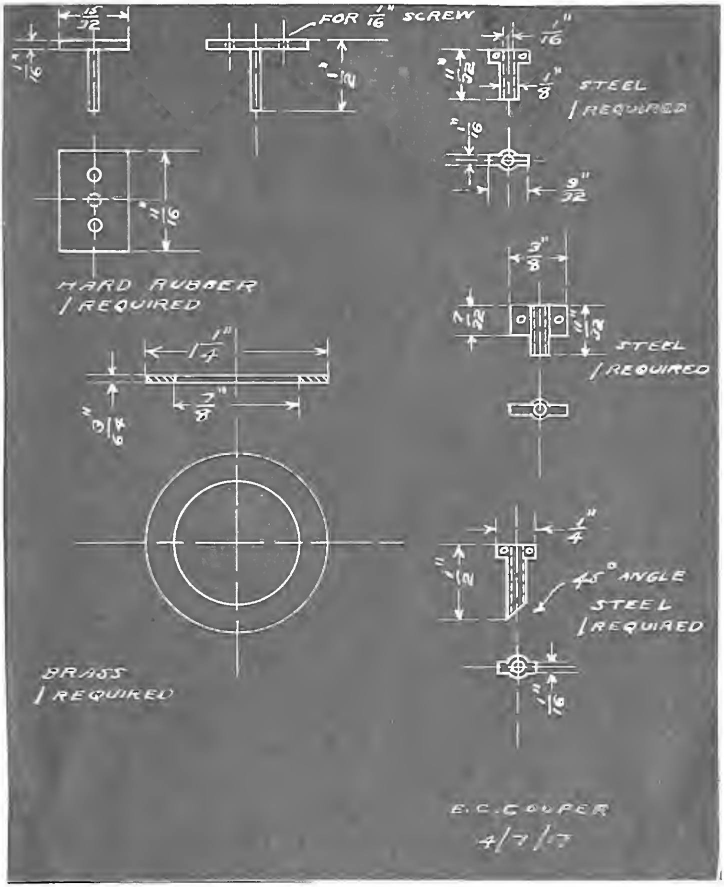
TAP FOR 1/8" SCREW
.185" DRILLED HOLE
MAGNET IRON: 1 RIGHT AND 1 LEFT REQUIRED
SEE ASSEMBLED DRAWING
.185" DRILLED HOLE
MAGNET IRON: 1 REQUIRED
TAP FOR 1/8" SCREW
BRASS: 1 PAIR REQUIRED
SEE DETAILS OF CUTOUT DEVISE
SCALE 12" = 1 FT.
E. G. COOPER
4/7/17

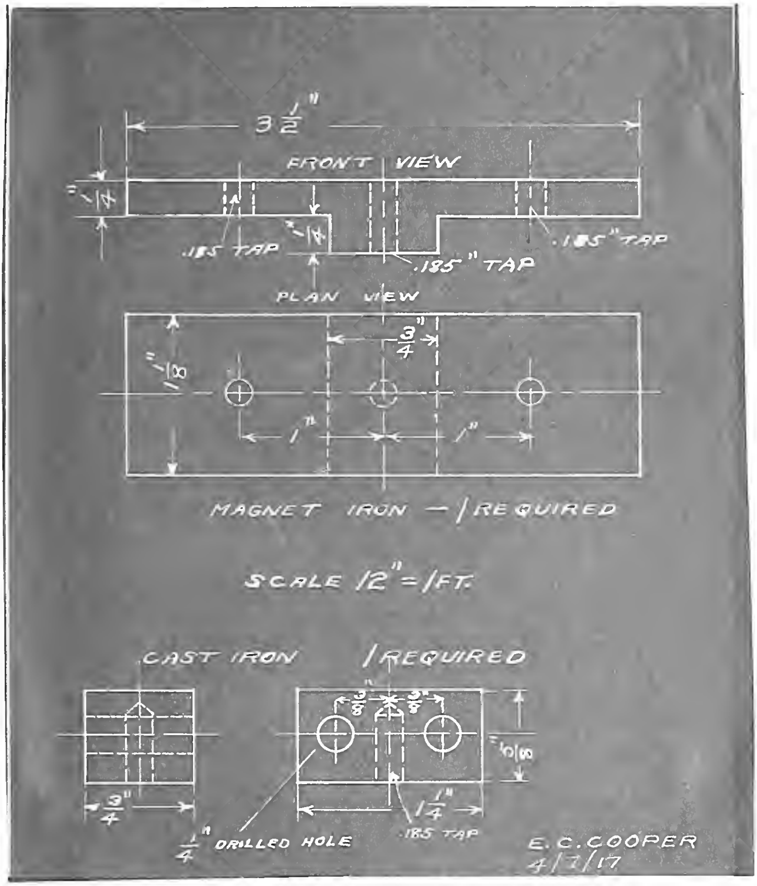


TAP FOR 1/8" SCREW
TAP FOR 1/8" SCREW
.185 DRILLED HOLE
.185 DRILLED HOLE
7/16"
3/16
2 3/16"
1 25/32"
13/32"
4"
1/4"
MAGNET IRON 1 REQUIRED
9/16"
.185" DRILLED HOLE
7/8"
15/32"
15/32"
7/8"
3/4
1/8"
1/16
1 21/32"
MAGNET IRON 1 REQUIRED
3 3/8"
3 3/8"
11/16
1 1/16"
1 1/16"
.185 DRILLED HOLE
7/16"
5/16"
SCALE. 12" = 1 FT.
E. C. COOPER
4/7/17


HOLE FOR 1/8" PIN
1/4" SCREW
1/8" DRILLED HOLE
MAGNET IRON
1 REQUIRED
1/16" DRILLED HOLE
BRASS
1 REQUIRED
SCALE 12" = 1 FT.
HOLE FOR 1/16" PIN
CAST IRON
1 REQUIRED
E. C. COOPER
4/7/17


1 25/32"
FOR 1/8" SCREW
7/8"
1 7/8"
7/8"
1/16"
ROUND TOP
15/16"
1 19/32"
15/16
27/32"
1/16"
3/4"
1 5/8"
1/8" TAP FOR 1/8" PIN
3/16"
BRASS
2 REQUIRED
CAST IRON 2 REQUIRED
SCALE 12" = 1 FT.
E. C. COOPER
4/7/17


FOR 1/16" SCREW
15/32
1/16
1/2"
1/16"
11/32"
1/8"
STEEL
1 REQUIRED
1/16"
9/32"
11/16"
HARD RUBBER
1 REQUIRED
3/8"
7/32"
11/32"
STEEL
1 REQUIRED
1 1/4"
7/8"
3/64"
1/4"
1/2"
45° ANGLE
STEEL
1 REQUIRED
1/16"
BRASS
1 REQUIRED
E. C. COOPER
4/7/17


FRONT VIEW
.185 TAP
.185" TAP
.185" TAP
PLAN VIEW
MAGNET IRON — 1 REQUIRED
SCALE 12" = 1 FT.
CAST IRON 1 REQUIRED
1/4" DRILLED HOLE
.185 TAP
E. C. COOPER
4/7/17

CALCULATIONS.

Calculations for 115 volt A.C. furnace controller:

(design of large magnet)

Assume,

2-1/2 vertical damper lift

10# maximum weight.

Main magnet,

1/4" movement

outside diameter of brass tubing containing core 7/8" A. W. G. #14

- - - - - - - - - - - - - - - - - -

leverage $= \dfrac{2.5}{.25} = 10$

Pull required of magnet

= 10# x 10 = 100#

Thickness of tube = .064"

dia. core = .875 - 2 x .064 = .75"

area core = $.785 \times 75^2$ = .54 sq. in.

Using "American Armature" steel manufactured by the American Sheet & Tin Plate Co.,

induction of 14,000 lines may be obtained with a corresponding magnetization force of 10 NI per cm. of length of core =

7.5 x 2.54 = 19 cm.

total number of NI turns for the steel =

10 x 19.0 = 190.

Assume 15^{o} angle of core

length of air gap =

$2 \times .25 \times 2.54 \times \sin 15^{o} = .329$ cm.

NI/cm. for air gaps $= \dfrac{B}{1.26} = \dfrac{14,000.}{1.26}$

= 11,100.

required NI turns for air gap =

.329 x 11,100 = 3,660.

Total NI = 3,660 x 190 = 3,850 say 4000.

Assume #25 wire (enameled outside thickness = .0139" - thickness of bare wire = .0179.

Assume 2 amperes

$\therefore$ 1000 turns required per coil.

assume length of winding space = 1-1/2"

No. turns per layer

$= \dfrac{1.5}{.0189.} = 79$

no. layers $= \dfrac{1000}{79} = 13$ layers

$13 \times 79 = 1025$ turns / coil.

Using paper between layers to protect the coil against rupture, the thickness of the winding equals

$13 \times .0189 \times .005 \times 5/16"$, assuming the paper between the layers to be .005" thick.

resistance equals $\dfrac{3.14 \times .1.18 \times 2{,}000 \times 32}{12}$

$= 19.8$ ohms.

Check for fusing current,

$I = 10{,}244 \; d \; 3/2$

$= 10{,}244 \times \overline{.0179} = 24.4$ amps.

Calculations for pull.

pull in dynes = $\dfrac{B^2 A}{8 \pi}$

$$P = \frac{14{,}000^2 \times 2 \times 3.46 \times 2.2}{8 \pi \times 1000} \quad \text{(pounds)}$$

$P = 121\#$

Check:

$$F = \frac{CSN_1}{l} + 2\,S\left(\frac{NI}{l_a C_1}\right)^2$$

$C = 0.009 \qquad C_1 = 2{,}600.$

$$F = \frac{.009 \times .54 \times 4{,}000}{1.5} \times .54 \left(\frac{4000}{1/8 \times 2{,}600}\right)^2 \times 2$$

$F = 13 + 164 \qquad 121 + 13 = 134\#$

Thus in the preceeding calculations 13# additional pounds must be added to allow for the solenoid effect. The 164# obtained from the latter part of the equation is far in excess of the truth, since the pull with short air gaps is only proportional to the square of the ampere turns until the saturation point has been reached. In order to make a liberal allowance, 4,000 turns were used

instead of the required 3,660, which accounts for the discrepancy in the formulas.

DESIGN OF SMALL MAGNET.

Assume 1/4 the area, and consequently 1/4 the pull of the larger magnet for the same number of ampere-turns and air gap.

$$\text{Area} = \frac{.54}{4} = .137$$

$$d = \sqrt{\frac{.137}{.785}} = .42''$$

Large magnet gives a pull of 121# for 1/16" air gap. Assume that small magnet is designed as plain external armature horseshoe magnet, without internal angle.

With an air gap of 1/4" the pull will be,

$$\frac{121}{4 \times 16} = 1.89\#$$

since the pull is inversely proportional to the square of the air gap.

Assume same size of wire and same number of N I turns on small magnet as on large magnet.

dia. winding small magnet = .66" (average).

$$\therefore \text{ resistance } = \frac{.66}{1.18} \times 19.8 = 11.1 \text{ ohms.}$$

Taking the dimensions from the drawing, the weight of the armature of the small magnet together with the pieces of the cut out mechanism attached to it, comes out to be about 1/8 lb.

Calculations for a direct current regulator, to be operated by 4 dry cells.

The general dimensions of the apparatus will be taken about the same as in the preceeding 110 volt calculation.

Assume 2 volts (4 cells)

" 20 amperes.

from drawing,

thickness of winding = 5/16"

inner dia. of winding = 15/16"

lengths of winding space = 1-1/2"

Required ampere turns = 40000

$$\text{no turns required} = \frac{4000}{20} = 200$$

100 turns required per coil

Assume #13 single covered copper wire.

$$\text{No. of turns per layer} = \frac{1.50}{.077} = 19$$

$$\text{no. layers} = \frac{100}{19} = 5$$

thickness of winding =

$$5 \times .077 \times \sin 60^\circ = .34$$

Total number of turns

$= 2 \times 5 \times 19 = 190$ turns.

mean dia. $= 13/16 \times .34 = 1.27$

Length of winding $= \dfrac{190 \times \pi \times 1.27}{12} = 63.5$ ft.

resi

resistance of #13 wire per thousand ft. at 770 f.= 2.04 ohms.

Assuming 4 day cells connected in two parellel groups, each group containing 2 cells in series,

$\dfrac{2}{.129} = 15.5$ amperes.

with six cells,

$\dfrac{3}{.129} = 23.2$ amperes

The approximate inductance of a magnet:

Ref. h Standard Handbook for Electrical Engineers. Page - 326.

$$I = \frac{\phi . R}{1.257 N} \quad \text{(amperes)}$$

$$R = \frac{1}{S} \left(\frac{C_i}{u} \times Ta \right) \quad \text{(oersteds)}$$

$$L = \frac{E}{2 \pi + 1} \quad \text{(henrys)}$$

ϕ = maximum value of the total flux.

N = total number of turns of wire

S = Cross sectional area of magnetic circuit in sq. cm.

T; = length of the iron circuit in cms.

Ta = length in cms of the air gap.

u = permeability.

Equations for the pull of magnets:

Ref. Standard Handbook, Page 330.

simple soleuloid:

$$F = \frac{C\ S\ N\ I}{L}$$

F = pull in lbs.

N = Total number of turns

I = current in amperes.

S = cross sectional area of core in square inches.

L = length of solenoid in inches

C = .0.009

Horse shoe magnet:

$$F = S \left(\frac{N\ I}{L_a\ C} \right)^2$$

F = pull in lbs.

S = area of core in inches

N = total number of turns

I = current in amperes

L_a = total length of air gap in inches.

C = 2.600

Equation for a stopped solenoid, or a magnet combining both the characteristics of a solenoid and horseshoe magnet:

$$F = \frac{C\ S\ N\ I}{L} \times S\left(\frac{N\ I}{L_2 \times C}\right)^2$$

Calculation of Inductance of Large Magnet.

$$R = \frac{I}{S} \left(\frac{l_1}{u} + la \right)$$

$S = .54 \times \overline{2.54}^2 = 3.46$ sq. cms.

$u = 1.400$

$l = 8 \times 2.54 = 20.32$

$la = \frac{2}{16} \times 2.54 = .318$ cm.

$$R = \frac{1}{3.46} \left(\frac{20.32}{1.400} \times .318 \right) = .0962 \text{ oersteds.}$$

$$I = \frac{\phi\ R}{1.27\ N} = \frac{14,000 \times 3.46 \times .0962}{1,257 \times 2000}$$

$= 1.85$ amps.

$$L = \frac{E}{2\pi \times 1.} = \frac{110}{2\pi \times 60 \times 1.85} = .158 \text{ henrys}$$

$2\pi \times \# = 6.28 \times 60 \times .158 = 59.5$

The virtual resistance of a circuit involving both resistance and inducatance is,

$$2 = \sqrt{R^2 + (2\pi f L)^2}$$

In order to have two amperes flow,

$$\frac{110}{R} = 2 \qquad R = 55 \text{ ohms.}$$

$$Z = \sqrt{19.8^2 + 59.2^2} = 61.1$$

$$\frac{110}{61.1} = 1.8 \text{ amperes}$$

In some cases cases 115 volts are used

$$\frac{115}{61.1} = 1.88$$

With 1.8 amperes the pull would be

$$F = \frac{.009 \times .54 \times 3{,}600}{1.5} \times 121 \times \frac{1.8^2}{22}$$

$$F = 11.7 \times 98 = 110\#$$

Thus for this design no condenser will be needed.

The inductance of the small magnet will be considerably smaller than that of the large magnet, and in order to prevent a current larger than the desired two amperes, a larger number of turns of smaller wire may have to be used, so as to increase the inductance and resistance.

It will be observed that the inductance will increase slightly as the air gap decreases. Ordinarily this effect would be to diminish the pull as the square of the diminishing air gap. But outside of any inductive effects, the magnet would increase its pull as the square of the diminishing air gap. Thus these effects would neutralize each other. However, the inductive effect will not increase as the square because the core will be saturated. Therefore there will be a considerable increase in pull as the armature approvides the core.

For mechanical reasons, and in order to increase the dependability of the mechanism, it may become necessary to increase the strokes of the magnets. This is a simple proposition in direct current magnets, but in alternating current designs the varying reluctance of the magnetic circuit will have to be taken into consideration. As the air gap decreases, the reluctance increases, the inductance decreases,

and the current increases. In the previous design the current would be about 5 amperes if there were no inductance present, since the resistance of the wires is twenty ohms. There will, however, be some inductance present since the core will never be entirely out of the coils. Solenoids are usually designed to utilize the maximum pull, which is obtained when the core is above one third inside of the coils. The inductance will be proportional to the distance the core is in the coils. Thus there may be two or three amperes excess at the end of the stroke, which, however, is not a serious objection. Instead of two amperes, four amperes may have to be allowed for. In some small residences and apartments, the meters are only designed to carry five amperes. In such cases, larger meters may be installed.

In the previous design, practically the same current values will be obtained if the stroke is lengthened to one half an inch, and the area of the core is increased. If mechanical reasons necessitate lengthening the

stroke, this may be accomplished by carefully manipulating the various quantities involved in the design. A condenser will never be necessary. Difficulties which may arise, will never be due to excess inductance, but rather to a deficiency of inductance.

Hysteresis and Eddy Current Loss.

Franklin & Esty give the following formula for the calculation of eddy current loss.

$Pe = \sigma V F^2 T^2 B^2$

Pe = eddy current loss in watts.

V = volume in cubic centimeters.

F = number of magnetic cycles per second.

T = thickness of laminations in centimeters.

B = maximum flux density.

ø = about 2.5×10^{-11}

Dr. Steinmetz gives the following equation for computing hysteresis loss:

$$P = \frac{K B_{max}^{1.6}}{10^7}$$

P = loss per cubic centimeter in iron for one cycle per second, in watts.

Bmax = maximum flux density in gauses.

K = a constant depending upon the material

K = about 0.003

In calculating the eddy current loss, calculations are made for each of the three different pieces, comprising the magnetic circuit, and the results added to give the final result.

1. Path thru top piece. Volume in square inches: = .50 x 1.13 x 5 = 1.97 cu. in.in cubic centimeters equal 1.97 x 16.3 = 32.1

T = 2.5 x .50 = 1.27 cm.

$Pe = 2.5 \times 10^{-1} \times 32.1 \times 3600 \times 1.62 \times 196 \times 10^{6}$

taking B as 14,000

Pe = 920 watts.

2. Path thru rectangular section:

cubic inches equals .25 x 4 x 2.38 = 2.38

T = .645 cms. cu. cm. = 2.38 x 16.3 = 38.8.

$$Pe = \frac{920 \times 38.8 \times 415}{1.62 \times 32.1} = 286$$

3. Path thru cylinders cubic cms =

$$\frac{2 \times 1.63 \times .285 \times 9 \times 16.3}{16} = 23.4$$

T = 2.54 x .75 = 1.91

$T^2 = 3.65$

$$P = \frac{920 \times 23.4 \times 3.65}{32.1 \times 1.62} = 1.495$$

Total:

1,495
286
920
2,701 watts.

From the above it will be seen that it will be impossible to operate one of these heat regulating mechanisms without carefully laminating the magnetic path, since with a 20 ohm wire resistance and 2 ampere, only 275 watts will be available to waste in core losses.

The 2,700 watts may be considerably in excess of the truth, since the formula used may not apply accurately to such thick lamination. However, even if the loss were only 500 watts, laminations would be necessary. For continuous service, all alternating current magnets are laminated. Without laminations, the magnets heat up rapidly. Electrical calculations do not always give the desired features in designs, and then considerable experimentation has to be done in order to perfect the mechanism. Whether or not laminations can be avoided in this case can be easily determined by experiment. We will be safe in saying that the designs will require laminations on alternating current; for although the service is only intermittant and the eddy

currents will cause no heating, still the power loss will prevent the desired current from flowing thru the winding.

Hysteresis loss:

$$Pn = \frac{.003 \times 14{,}000^{1.6}}{10^7}$$

$$Pn = \frac{.003 \times 4{,}470{,}000}{10^7} = .00134$$

Total Pn = .00134 x 60 x 94.3 = 7.59 watts.

Thus the hysteresis loss is practically negligable.

$$\text{Wt. of material} = \frac{7.5 \times 94.3}{454} = 1.55 \text{ \#}$$

Follansbee Bros. Laminated core material loss at 60 cycles and 14,000 induction is 1.7 watts / pound, including both hysteresis and eddy current loss.

1.55 x 1.7 = 2.64 watts.

Thus with laminated material core losses will be practically negligable.

REQUIREMENTS OF THE ELECTRICAL CODE.

In the installation of electric heat regulating systems, all wires have to be laid in accordance with the ordinary rules and regulations governing house wiring. A regulating motor does not come under the classification "portable apparatus", and hence flexible cord cannot be used on 110 volt circuits. The wires have to be laid in conduits. The fact that the wires have to be laid in conduits is a matter of considerable importance in finished buildings. Wires from batteries or bell ringing transformers do not have to be laid in conduit but may be laid bare, provided, they are grounded. This fact may be used to good advantage in finished buildings. Bell ringing transformers must not have a capacity of over 25 watts, or a current output of over 10 amperes.

RÉSUMÉ

It may be seen from the preceding pages that there are big possibilities of improvement in the present methods of electrical temperature control in residences, apartment buildings, stores, and street cars. The reason why the thousands of houses, apartment buildings, etc., in the world are not equipped with automatic heat regulators, at the present time, is due to the fact that the motor end of the regulating systems has not been as yet perfected so as to be absolutely dependable and of simple construction. The bimetallic electrical thermostats have proven to be entirely satisfactory, and easily adjusted. The trouble lies at the other end of the line.

As a rule the current cannot be allowed to flow continuously in thermostatic systems because of the eccessive power consumption occassioned. The stumbling block during seventy five years or so of experimental work along heat

regulating lines has been to obtain a suitable automatic cut out mechanism which will prevent excessive power consumption. A solution of the problem has been presented in this thesis, whereby two alternating, or direct current horseshoe magnets are to be used in conjunction with a relay. One magnet is to act as a power magnet, and the second is to alternating hold, and release the first.

No springs are to be used in the apparatus, except in special cases. All such elements of unreliability, as springs, wearing of parts and contacts, are to be eliminated by special provisions in the design of the apparatus. The contacts are to be held in their positions by gravity and small chains, in place of springs; the only part of the apparatus that is subject to wear is to be specially protected, by a novel arrangement of wiring, and an extra contact; excessive wearing of contacts is to be prevented by sending only low voltage and small currents

through the contacts; any slight wear that may be occasioned at the contacts, is to be compensated for so that the life of the contacts will be indefinite; and finally, 110 volts are to be broken only at the relay where a very large wearing effect may be easily taken care of. The contacts are to be made of tungsten.

B I B L I O G R A P H Y.

During this research the writer consulted freely many engineering text books, hand books, periodicals and catalogues. An illustrative problem on the design of lifting magnets, in "Gray's Principles and Practice of Electrical Engineering proved very useful. Mr. C. R. Underhill's book on electromagnets, together with his section in the "Standard Handbooks for Electrical Engineers" proved invaluable.

In order to make this research exhaustive the writer made a careful study of the records of the United States Patent Office, beginning with the first crude attempts at heat regulation about one hundred years ago.

The following patents are especially interesting in this connection, and may be found on file in the Chicago Public Library, or may be obtained from the commissioner of patents, Washington, D. C.

1,162,372	1,193,271	342,013

467,153	949,286	301,059
466,153	1,175,864	297,937
425,625	949,285	450,927
1,183,018	332,066	1,065,393
1,198,737	961,734	1,170,727
924,235	373,104	773,078
373,103	594,346	754,465
568,950	616,358	560,703
600,966	551,951	365,600
542,133	430,633	382,165
845,281	379,201	415,871
378,137	1,100,077	10,802
1,050,431	352,874	1,176,727
352,057	1,173,764	351,702